Development of nanostructure materials for high performance gas sensors

VBL researcher: Zhifu Liu

I Introduction

Oxide semiconductor gas sensors are increasingly demanded for industrial safety, environmental monitoring, and process control because of their small size, low cost, and compatibility with microelectronic processing. To achieve high performance oxide semiconductor gas sensors, large effective surface area and small grain size are preferred. Therefore, the large surface-to-volume ratio makes quasi-one-dimensional (1D) and nanoporous materials as ideal candidates for gas sensing applications. For example, the 1D nanostructure of well-established gas sensing materials such as SnO_2, ZnO, WO_3 and In_2O_3 showed higher sensitivity, faster response, and/or enhanced capability to detect low concentration gases compared with the corresponding thin film materials. Here, we developed several kinds of high surface area and 1D oxide nanostructures. Most of these materials showed very promising gas sensing performance. We believe that some of the materials can be commercialized after further step investigations, for example, in selectivity and life time.

II Main results

2.1 Dealloying derived synthesis of high surface area WO_3 films [1, 2]

We fabricated the high surface area WO_3 nanostructural films by dealloying with subsequent thermal oxidation. Sputtered amorphous $W_{0.68}Cu_{0.32}$ alloy films were dealloyed in HNO_3 solution where Cu was selectively removed and W self-assembled into cross-linked cubic phase W nanoflakes. Then, the dealloyed films were oxidized at 500 °C for 8 h in air. The obtained WO_3 film has a monoclinic structure and shows high surface area (Figure 1a). The NO_2-sensing of the WO_3 films was investigated. Figure 1b shows the dynamic responses of the WO_3 film-based sensor to NO_2 gas at 200 °C. The sensor show reversible responses to the NO_2 pulses. The sensor responds fast and the response time is less than tenth of that of conventional sputtered WO_3 thin film sensor.

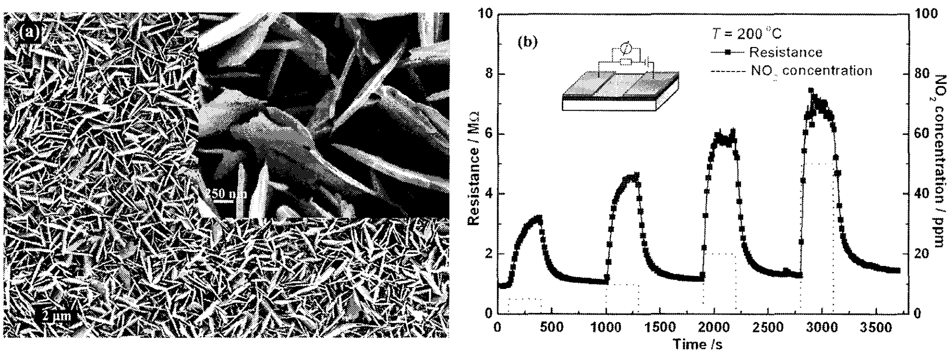

Figure 1 (a) SEM image of dealloyed derived WO_3 film; (b) NO_2-sensing of the WO_3 film.

2.2 TeO_2 nanowires and their gas sensing [3, 4]

TeO_2 nanowires were successfully synthesized by a simple reactive thermal evaporation method using pure Te metal as the source material. The study on synthesis process indicates an optimal synthesis temperature of 400 °C. Structural characterization using X-ray diffraction and transmission electron microscopy (Figure 2 A) shows that the TeO_2 nanowires have a single crystal tetragonal structure. The gas sensing measurements indicate that TeO_2 nanowires have a p-type electrical conduction and can reversibly response to NO_2 gas at room temperature (Figure 2B). And also, TeO_2 nanowires show reversible sensing to H_2S and NH_3 gas at room temperature. The p-type conduction and the room temperature response are very promising for gas sensor application.

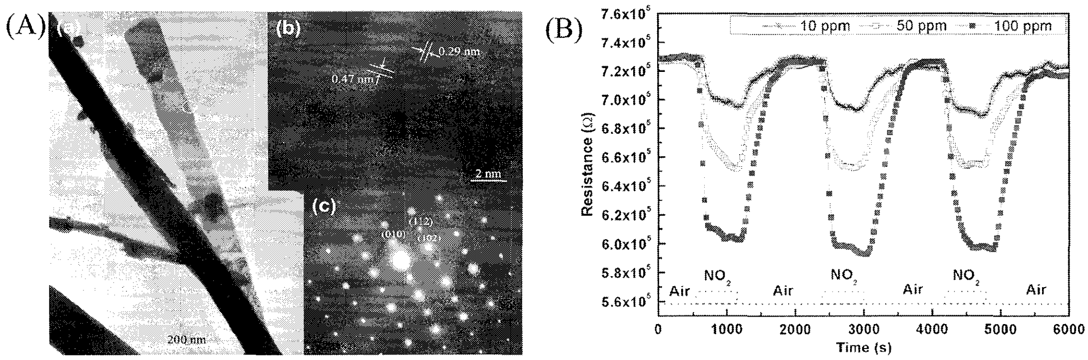

Figure 2 (A) TEM images of TeO_2 nanowires; (B) Response of TeO_2 nanowires to NO_2 gas at RT.

2.3 Ga_2O_3 nanowires and their gas sensing [5]

We synthesized gallium oxide nanowires by a chemical thermal evaporation method using gallium metal as a source material. Structure characterizations indicate that the obtained nanowires are well-crystallized single phase monoclinic Ga_2O_3. The Ga_2O_3 nanowire gas sensors show reversible response to O_2 and CO gases in a working temperature range of 100-500 . A peak response is found at 300 for O_2 gas and the peak response appears at 200 for CO gas. The results demonstrate the possibility of using the Ga_2O_3-based gas sensor at low working temperature field.

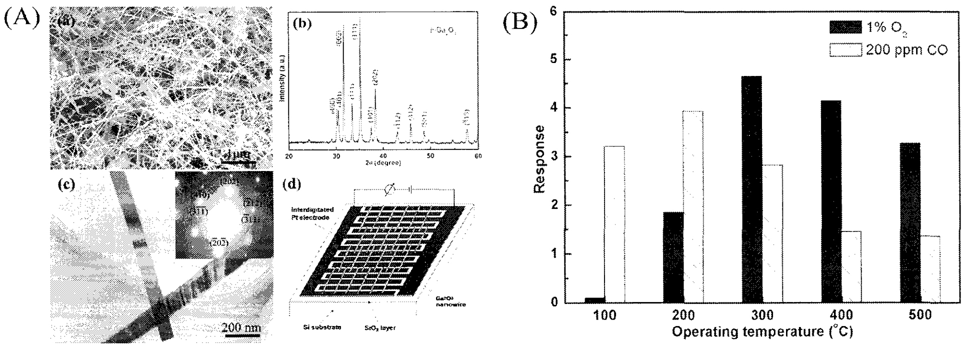

Figure 3 (A) SEM, XRD, TEM of Ga_2O_3 nanowires and nanowires based gas sensor; (B) Sensitivity to O_2 and CO at different temperatures.

References:

[1] Zhifu Liu, Toshinari Yamazaki, et al., Chemistry Letters, 37(2008) p296.

[2] Zhifu Liu, Toshinari Yamazaki, et al., Journal of Physical Chemistry C, 112(2008) p1391.

[3] Zhifu Liu, Toshinari Yamazaki, et al., Applied Physics Letters, 90(2007) p173119.

[4] Zhifu Liu, Toshinari Yamazaki, et al., Japanese Journal of Applied Physics, 47(2008) p771.

[5] Zhifu Liu, Toshinari Yamazaki, et al., Sensors and Actuators B, 129(2008) p666.